

Hot water is used in Federal facilities for hand washing, showering, janitorial cleaning, cooking, dishwashing, and laundering. Facilities often have significant hot water needs in one or more locations, and many smaller needs scattered throughout the facility. Methods for reducing the energy used to generate hot water include: maintaining equipment and insulation; reducing hot water use and water temperatures; reducing heat losses from the system; and utilizing waste heat sources and appropriate technologies, including solar water heating.

Action Moment

Reduce demand first through efficiency measures and by matching the water temperatures to the task. Then, consider heat source and new equipment to lower operating costs further. Installing higher-cost, new water-heating technologies, such as waste heat recovery, is often done in conjunction with air conditioning equipment changes. Plan ahead and select a technology for use in the event the existing system fails.



Water Heating Technologies

Several water-heating technologies are listed below.

- 1 Solar thermal water heating** captures the energy from the sun for heating water. Direct systems circulate domestic water directly into the panels. Indirect solar systems use heat exchangers and food-grade antifreeze solutions to eliminate freeze damage and hard water scaling of the panels.
- 2 Standard electric water heaters** store electrically heated water in insulated storage tanks. Many older tanks have poor insulation compared to today's standards and should be replaced or jacketed externally with additional insulation.
- 3 Tankless electric or on-demand electric heaters** eliminate standby losses by heating water



Solar thermal water heating can meet hot water demand at very low operating cost. Flat plate collectors are in the middle of the photo. Also shown are PV panels on the flat portion of the roof.

only during use. They are located at the point of use, and are convenient for remote areas having only occasional use. However, they can increase electrical power demand charges if hot water is used during peak periods of the month.

- 4 Steam-fired water heaters** utilize centrally produced steam for heating water. These units are popular in commercial kitchens where steam is also used for cookers. Where boilers must be kept operating during summer months to supply small amounts of steam for kitchen purposes, changing to alternative water heating would be extremely cost effective.
- 5 Standard gas-fired water heaters** use natural gas or propane burners located beneath storage tanks. Standby losses tend to be high because internal flues are uninsulated heat-exchange surfaces.
- 6 Condensing gas water heaters** are extremely efficient gas units that capture the latent heat of vaporization from the combustion gases. Flue gases are cool enough to permit venting with special PVC pipe.

7 **Tankless gas water heaters** are installed at the point of use. These on-demand heaters may be good options for remote sites where there is adequate gas piping, pressure, and venting.

8 **Air-source heat pump water heaters** are specialized vapor-compression machines that transfer heat from the air into domestic water. Commercial kitchens and laundries are excellent opportunities because both indoor air temperatures and hot water needs are high. In the process of capturing heat, the air is both cooled and dehumidified, making space conditions more comfortable. Air-source heat pumps are only recommended if the air source is warm with waste heat.

9 **Water-source heat pump water heaters** are dedicated heat pumps that heat domestic water from energy captured from a water source. The heat source may be groundwater that is used for its stable year-round temperature, or a low-grade waste heat source at a temperature lower than the desired domestic water temperature.

10 **Waste heat water heaters**, also known as desuperheaters, are connected to air conditioners, heat pumps, or refrigeration compressors. Hot refrigerant gas from the compressor is routed to the gas side of the unit's heat exchanger. Water is essentially heated for free whenever the air conditioner, heat pump, or refrigerator compressor is operating. When a waste heat water heater is connected to a heat pump that is operating in heating mode, some of the heat pump's capacity is devoted to water heating.



Insulate tanks and hot water lines that are warm to the touch. Only recently have manufacturers installed adequate amounts of insulation on water tanks. Hot water lines should be continuously insulated from the heater to the end use. Cold water lines also should be insulated near the tank to minimize convective losses.

Limit operating hours of circulating pumps. Large facilities often circulate domestic hot water to speed its delivery upon demand. Both the cost of operating the pump and heat losses through pipe walls will be reduced.

Install heat traps. Heat traps are plumbing fittings that cut convective heat losses from water storage tanks.

Install hot water heaters near the points of most frequent use to minimize heat losses in hot water pipes. This location will not necessarily be where the most hot water is used.

Eliminate hot water leaks. Delays in repairing dripping faucets often lead to more expensive repairs. Failure to replace faucet washers promptly will cause metal-to-metal contact between the valve stem and valve seat.

Repair hidden waste from failed shower diverter valves that cause a portion of the water to be dumped at a user's feet. This leakage is usually not reported to maintenance teams.

Reduce hot water temperature. Temperatures can be reduced to 60°C (140°F) for cleaning and laundering.



Low-flow fixtures. Some low-flow showerheads and faucets atomize water into tiny droplets, making warm water feel cold. Only purchase, quality low-flow heads that fully drain when off. These types have high user acceptance.

Water tank. Turning down the hot water temperature below 120°F (49°C) for conservation may cause indoor air quality problems by allowing Legionella to grow inside domestic water tanks.

Contacts

The FEMP Help Desk at (800) DOE-EREC can provide many publications about energy-efficient water heating.

Heat recovery is the capture of energy contained in fluids or gases that would otherwise be lost from a facility. Heat sources may include heat pumps, chillers, and steam condensate lines, and even hot air associated with kitchen and laundry facilities. Heating water for domestic use offers the best waste heat recovery opportunities under the following conditions: (1) hot water demand must be high enough to justify equipment and maintenance costs; and, (2) waste heat must be of high enough temperature to act as the heat source.

Action Moment

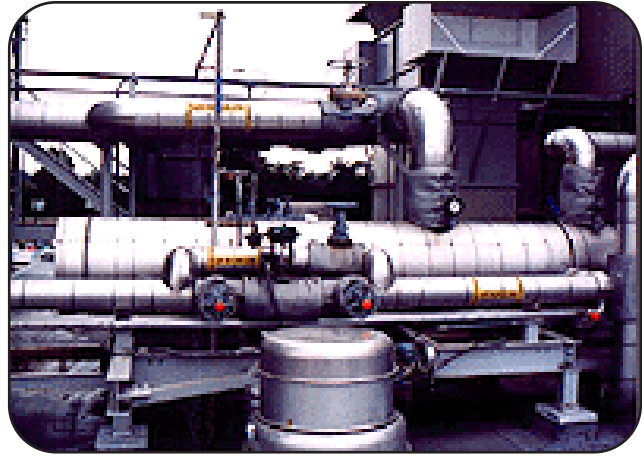
Large facilities such as hospitals and military bases often have the perfect mix of waste heat and demand for hot water to justify using waste heat recovery systems for water heating. Consider waste heat recovery whenever adding or replacing large heating or air conditioning equipment. For example, double-bundle chillers can easily provide for the recovery of heat normally lost to a cooling tower.



Technical Information

Opportunities for capturing waste heat depend upon the temperature of the waste heat source. Where a water temperature of 60°C to 82°C (140°F to 180°F) is required for domestic applications, waste heat sources with higher temperatures should be used. Lower-temperature sources such as hot kitchen air or drain water may require mechanical systems to concentrate the heat. Otherwise the waste heat may be used to pre-heat the water before another fuel is used to elevate the temperature to the desired level.

1 Hot gas heat exchangers. The refrigeration cycle of air conditioners and heat pumps provides an opportunity to capture heat for heating domestic water. HVAC compressors concentrate heat by compressing a gaseous refrigerant. The resultant superheated gas is normally pumped to a con-



Heat recovery captures heat that would otherwise be lost to the environment.

denser for heat rejection. However, a hot gas-to-water heat exchanger may be placed into the refrigerant line between the compressor and condenser coils to capture a portion of the rejected heat. In this system, water is looped between the water storage tank and the heat exchanger when the HVAC system is on. Heat pumps operating in the heating mode do not have waste heat because the hot gas is used for space heating. However, the heat pump system can still heat water more efficiently compared to electric resistance heating.

2

Double-bundle condensers. Some chillers have condensers that make water heating with waste heat recovery possible. Double-bundle condensers contain two sets of water tubes bundled within the condenser shell. Heat is rejected from the system by releasing superheated gas into the shell and removing heat as the refrigerant condenses by one of two methods. During the heating season, water pumped through the “winter bundle” absorbs heat where it is used for heating domestic water or heating the perimeter of the building. During the cooling season, water pumped through the “summer bundle” rejects heat to the cooling tower after hot water needs are met.

3 Heat from engines. Heat exchangers can be placed on exhausts of reciprocating engines and gas turbines to capture heat for water heating or steam generation. Water jackets may also be placed on engines in order to capture heat from the engine and exhaust in series. Some equipment also acts as a silencer to replace or supplement noise reduction equipment needed to meet noise requirements. Systems for domestic heating are unpressurized, but temperatures above 99°C (210°F) are possible with pressurized systems. Designers must be careful that the pressure drop is less than the back pressure allowed by the engine manufacturer.

4 Heat from boiler flues. Hot flue gases from boilers can provide a source of waste heat for a variety of uses. The most common use is for pre-heating boiler feed water. Heat exchangers used in flues must be constructed to withstand the highly corrosive nature of cooled flue gases.

5 Hot drain heat exchangers. Energy required to heat domestic water may be reduced by pre-heating with drain water. Kitchens and laundries offer the greatest opportunities for this type of heat recovery since water temperatures are fairly high and schedules are predictable. These systems must be designed to filter out waste materials and ensure the heat exchange are not fouled by the dirty waste water.

6 Steam condensate heat exchangers. Buildings with steam systems for space heating or kitchen facilities may recover some of the heat contained in hot condensate. Condensate is continuously formed in steam systems when steam loses heat in the distribution lines or when it performs work. A condensate receiver reduces steam to atmospheric pressure to allow reintroduction into the boiler. A heat exchanger located in the condensate return before the receiver can capture condensate heat for heating water.

7 Heat pump water heaters. Rooms containing laundries and food preparation facilities are often extremely hot and uncomfortable for staff. Heat from the air can be captured for heating water by using a dedicated heat pump that mechanically concentrates the diffuse heat contained in the air. These systems are discussed in section 3.7.

8 Refrigeration equipment. Commercial refrigerators and freezers may be installed with condensing units at one location. This will enhance the economic feasibility of capturing heat from hot refrigerant gases for water heating.

References

Center for the Analysis and Dissemination of Demonstrated Energy Technologies, "Heat Exchangers in Aggressive Environments," Analysis Series # 16, 1995.

Heating water using the sun's energy is a renewable technology that is practical in almost any climate. In many parts of the United States, solar systems can meet the total hot water demand during summer months. In the winter and other times when collection rates are lower than hot water demand, alternative heat sources supplement solar heating.

Action Moment

Solar water heating should be considered to replace electric water heating when water demand is both high enough to justify initial costs and fairly constant throughout the week. Good candidates are laundries, hospitals, dormitories, gymnasiums, prisons, and other regularly-used shower facilities. Swimming pools are good summer season applications for solar water heating systems.



Solar water heating is a proven technology that directly substitutes renewable energy for conventional water heating. This array of parabolic trough collectors was paid for through an Energy Savings Performance Contract (ESPC).



Technical Information

Solar thermal water heating systems come in various configurations suited for different climatic zones and applications. The two basic components are collectors, usually mounted on the roof or ground, and an insulated storage tank. Active systems contain mechanical pumps for circulating the collection fluid which is either plain water, or water containing antifreeze. Passive systems do not have pumps. There are three basic configurations:

1 **Passive systems** do not use pumps or other mechanical devices, have relatively inexpensive maintenance requirements, and can be used in sun belt areas where freeze protection is a modest concern. Circulation relies on the buoyancy of warm water rising from the collector to the tank, which is always located above the collector. Heat pipes—sealed tubing systems containing refrigerant—can also be used for heat transfer from panel to tank. The storage tank may be located remotely from the collector (thermosyphon systems) or as part of the panel (integral collector/storage—ICS). With ICS systems, roof structures must be strong enough to

support the weight of water-filled collector tanks.

2 **Direct or “open loop” systems** are simple, very efficient, and suitable for mild and moderate climates with good water quality. In direct systems, water ultimately consumed by the end users is heated directly in the collector. Some systems make clever use of photovoltaic-(PV) powered direct-current pumps sized to adjust the flow of circulating fluid to sunlight conditions. Damage to collectors is a concern if water is hard or corrosive. Also, direct systems must be protected from freeze damage. Direct Systems are especially applicable to swimming pool water heating.

3 **Indirect or “closed loop” systems** are dependable and suitable for all climates. Indirect systems circulate nontoxic antifreeze through the closed “solar loop” consisting of the collector, piping, and heat exchanger located at the storage tank. Antifreeze in the collector and exposed piping ensures protection from freeze damage, corrosion, and scaling in the collector. Like direct systems, indirect systems may use PV-powered pumps.



Freeze protection strategies should be provided in all but tropical climates, there are four basic strategies:

1 In **Drainback Systems**, water from collectors and exposed piping drains into a reservoir whenever the circulating pump is turned off. This provides reliable freeze protection even when electrical power fails.

2 **Draindown Systems** dump water from a collector onto the ground or into a drain when triggered by near-freezing temperatures. They also may be manually drained in case of power failure during freezing. Draindown systems historically have been the least reliable.

3 **Recirculation Systems** utilize warm water from the storage tank to circulate into the collectors during freezing weather. They should be considered only in mild climates.

4 **Indirect Systems containing antifreeze** are reliable for use in any climate and are very effective at avoiding freeze damage.



Collectors for domestic water heating are available in three basic types:

1 **Flat plate collectors** are the most common and consist of insulated rectangular frames containing fluid-filled tubes mounted on dark-colored absorber surfaces. Highly transmissive tempered glass covers the absorber.

2 **Evacuated tube** collectors utilize a tube-within-a-tube design similar to a thermos bottle. A vacuum between the fluid-filled inner tube and glass outer tube allows maximum heat gain, minimum heat loss, and very high temperature potential.

3 **Parabolic-trough collectors** are efficient but can be expensive. Their most cost-effective use is in large systems such as those found in prisons where their cost is less than the cost of flat plate collectors. Long, parabolic-shaped mirrors track the sun and focus its light onto centrally located fluid-filled tubes. Because the sunlight is focused,

diffuse light cannot be used, making this a poor choice for humid climates.



Solar systems should be tested and certified by independent groups such as the Solar Rating and Certification Corporation (SRCC) or the Florida Solar Energy Center (FSEC).

Colder climatic zones require the use of more collector area and the use of indirect systems having superior freeze-protection capabilities.

Removing trees to accommodate sunlight access for solar collectors may be a net energy loser if there is substantially more heat gain through exposed windows when air conditioning.

At times of the year when collectors harvest sunlight very efficiently, water temperatures may be above 60°C (140°F). Ensure that mixing valves are installed to keep users from being scalded.

On direct systems, collectors may require periodic treatment with a nontoxic solution, such as diluted vinegar, to remove scaling buildup that inhibits heat transfer and efficiency.



The economics of installing solar water heating depend on the cost of alternative fuels such as electricity. Hot water demand, patterns of usage, and availability of solar energy are also key considerations. Retrofitting solar water heating into existing buildings is complicated by the need to provide access for running pipes and space in mechanical rooms for larger storage tanks. Solar water heaters can provide 40% to 80% of the annual hot water needs.

References

Department of Energy, Federal Energy Management Program, "Solar Water Heating," *Federal Technology Alert*, Washington, DC, Sept. 1995.

Contacts

The FEMP Help Desk at (800) DOE-EREC or at <http://eren.doe.gov/femp> can provide technical assistance and information about financing via Energy Savings Performance Contracting.

Appropriate control systems allow facility managers to automate functions that would be impractical or impossible to control manually. Automatic systems are useful with lighting, air distribution systems, chillers, boilers, heat pumps, pumping systems, compressed air systems, water heating, and other major energy-consuming equipment. Controls may be simple and inexpensive, or complex and costly. Simple controls, including time clocks, occupancy sensors, photocells, and programmable thermostats are discussed in this section. More sophisticated computer-based energy management systems (EMS), that monitor hundreds or thousands of “points” throughout a facility, are discussed in section 3.8.1. Some control systems designed to reduce peak electrical demand and lower utility bills are presented in section 3.8.2.

Action Moment

Facility managers should consider automatic controls and sensing technology when equipment can be turned on, shut off, or modulated based on schedules, temperatures, pressures, light levels, or the presence of occupants. HVAC and lighting are prime candidates for automatic controls.



Technical Information

The following is general information about some of the common controls available to help reduce energy consumption.

1 Time clocks are electrical or electromechanical devices that can turn equipment on and off according to a schedule. Small loads can be switched directly and large loads can be controlled indirectly through the use of relays. Many time clocks are 24-hour devices that repeat programs every day. Some have weekly and even annual wheels that allow more complex programming patterns. Although it will minimize wiring costs, locating time clocks near the circuits they control is not necessary.

2 Occupancy sensors detect the presence of people by sensing heat (infrared), motion (ultrasonic), or sound. Some systems directly control small lighting loads at line voltage and directly replace wall switches. Others are part of systems that may include several sensors, control logic, and interface to the load. These types of sensors are discussed in section 3.4.4 of this guide. Facilities with EMSs may use occupancy sensors to control lights and HVAC operations that have complex programming involving many functions.

3 Programmable electronic thermostats allow facility managers to reset heating and cooling setpoints for different operating modes. Daytime, nighttime, and weekends typically have different target temperatures in order to allow the building temperature to drift appropriately when unoccupied.

4 Spring-wound timers are simple devices that automatically turn off loads after a predetermined number of minutes or hours. They can be used to control bathroom exhaust fans allowing them to remove moist air after showering, and preventing continuous operation.

5 Photocells are devices that open and close switches in response to light levels. Some photocells are not very sensitive to low light at dusk and dawn. They may switch lights on in the evening before they are needed. This wastes energy, and in some cases, demand charges will also be higher.



Power outages disrupt schedules of electromechanical time clocks because the time setting is lost. Daylight savings time shifts also require resetting the time. Consider solid-state time clocks with rechargeable batteries.

Standard time clocks usually do a poor job of controlling exterior lights because they lose the current time when time changes or power fails. Simple time clocks do not account for daily changes in sunset and sunrise.

EMS systems can be prone to problems with electrical power quality, particularly during power outages.

To avoid injury, signs indicating the control mechanism and disconnect switches should be placed near equipment under automatic control.



When purchasing programmable thermostats made for use with heat pumps, ensure they have “ramped recovery” features for heating. Ramped recovery slowly brings the building up to the target temperature without engaging the supplementary electric strip heating.

Facility managers should document all the automatic controls in their facilities. They should record: the locations of the controls; the equipment they control; and the need for resetting the time or program as seasons change, as time changes for daylight savings, or after power outages.

Electrically combining time clocks and photocells may provide a good way to program the needed exterior lighting logic, such as “on at sunset, off at 10:00 P.M.” Facilities with EMSs should be able to implement this type of software logic.

Energy management systems (EMSs) improve efficiency by monitoring conditions and controlling energy-consuming equipment. An EMS is typically applied to the largest electrical loads, including HVAC equipment, cooling towers, pumps, water heaters and lighting. Control functions may include basic stop/start functions or more complex chiller optimization routines. An EMS can be used on new or existing facilities and can interface with existing controls, such as pneumatic damper actuators. EMSs typically reduce the cost of doing business by reducing labor costs. EMSs can have very favorable paybacks, especially where existing control systems are lacking or have problems. By tracking system operation using an EMS, a facility manager can perform diagnostics and optimize system performance.



Energy Management and Control Systems can monitor and control equipment throughout a facility from a single location.

Action Moment

Facility managers should consider installing an EMS system in any facility expansion. EMS retrofits are often justified in existing buildings, and can involve improving chiller or boiler controls, adding economizer cycles, controlling lighting loads, and limiting electrical demand. An EMS can be particularly reliable for very large or widely dispersed facilities.



Technical Information

An EMS can perform various functions, from simple single-point control to multifunction systems with complex decision logic. Fully functional EMSs provide the greatest potential for maximum energy and cost savings.

1

Hardware varies in complexity. Simple systems include actuators that switch or change loads according to signals from local controllers that contain control logic. More sophisticated systems add sensors or monitoring points, field termination panels for minimizing control wiring, modems, communication links, and central computers. Software often includes user interfaces

that graphically depict equipment, sensors, and controls.

2

Distributed or networked systems combine the reliability of local controllers with the advantages of facility-wide monitoring. Centralized control provides facility engineers an immediate interface with remote equipment, and allows quick diagnosis of problems and quick response to complaints.



Functional Capabilities

Many scheduling, optimizing, and reporting functions are available on EMSs:

1

Start/stop controls will limit operating hours of equipment according to predetermined schedules.

2

Optimum start/stop controls delay bringing equipment on-line until the latest possible time. This is particularly useful in limiting HVAC operation.

3 Temperature setback/setup saves energy by allowing building conditions to drift within limits during unoccupied periods.

4 Economizer controls turn off chillers during mild weather and allow outside air to provide space conditioning.

5 Enthalpy control provides more sophisticated economizer control that is based on both temperature and humidity.

6 Supply temperature reset modulates circulating water temperature based on load sensors and program logic.

7 Boiler optimization balances fuel and combustion air with heating load variations.

8 Duty cycling can help reduce utility peak demand charges by turning off equipment a predetermined percentage of the time.

9 Demand limiters shed nonessential equipment such as water heaters to reduce peak power demand to a preset level.

10 Alarm functions alert operators to conditions outside pre-established ranges.

11 Monitoring provides the capability to track: (1) equipment run-time and other parameters for proactive maintenance; and, (2) energy use for cost containment.

12 Load management controls stage the start-up of large equipment to avoid power peaks.



Train key employees to use the EMS once it is installed.

Have a qualified engineering firm design specifications before bidding any EMS.

Require the vendor to fully demonstrate the system and all software before delivery. Video-tape the demonstration and training for use during refresher training.

Design expansions of EMSs to utilize a single user interface system in order to avoid confusing the operators.



New EMS systems will not necessarily interface properly with existing controllers and other components intended to remain in place.

Be careful with “custom built” systems. Purchase proven systems and software with a good track record. Request systems with open protocols to improve compatibility with future systems.

Reliance solely on the EMS console can lead to misdiagnosis. For example, a temperature alarm would prompt the operator to check position of the VAV damper for that zone. If the sensor indicated that the damper was full open and yet the zone was too hot, the operator might reset the chilled water temperature. However, the combination of a stuck damper (cutting off airflow) and a loose damper shaft (allowing the control system to believe the damper is operating normally) might be the real problem. This situation could easily fool both the control system and the operator.

Use in-house staff for day-to-day service requirements, provided staff is adequate and well trained. Service contracts can be very expensive and should be used only when absolutely necessary.

Sensors should be checked and calibrated on a regular maintenance schedule. Failed sensors and false readings can waste considerable energy.

References

Electric Power Research Institute, “Energy Management Systems,” (Technical Brief TB.EMU.121.4.87), Palo Alto, CA (510) 934-4212

Utility bills for large facilities include demand charges that can amount to one-third of monthly electricity costs. Demand is measured in kilowatts and is the average electrical load over a small period of time, usually 15 or 30 minutes. Facilities are billed for the largest peak demand during the billing period. Electrical demand peaks can be lowered in several ways: shedding unneeded loads, rescheduling loads, staging equipment start-up, generating power on site, or switching to another fuel.

Action Moment

Facilities with low load factors or steep load-duration curves are the best candidates for cost-effective peak shedding. Facilities already using energy management systems (EMSs) may have most of the hardware and software needed to institute a load shedding program.



Technical Information

Utility tariffs usually encourage demand control and load shifting. Facility managers should understand how their facilities are charged for power and energy. Three elements to examine are as follows:

1 Demand charges are based on the highest monthly power peak, measured in kilowatts (kW). All but the smallest facilities will be billed for demand. This charge reflects the electric utility's infrastructure cost of power generation and transmission and the more expensive fuels used in peaking units. Summer-peaking utilities tend to have higher summer demand charges, and winter-peaking utilities have higher demand charges during winter months.

2 "Demand ratchets" are minimum demand bills based on some percentage of the highest peak power metered over the preceding year. Thus, one month's high demand can impact monthly charges for an entire year.

3 Time-of-Use (TOU) tariffs offer discounted rates for power used at times the utility establishes



Thermal storage on HVAC systems is effective at cutting peak electrical demand.

as off-peak. The difference in energy charges (kWh) between on-peak and off-peak power can be a factor of two to four.



Demand shedding or peak shaving strategies include: purchasing smaller, efficient equipment; altering the on-times of existing equipment; switching fuels at peak times; and generating power on-site. Some popular strategies are listed below:

1 Duty cycling strategies attempt to limit the operation of equipment to certain times within a utility's demand period. Duty cycling has limited application because of stresses on frequently cycled equipment, and the effect on the building or its systems. For instance, duty cycling of cooling tower motors would allow the chilled water temperature to rise. Cycling a ventilation fan might compromise indoor air quality or adversely affect building pressures.

2 Demand limiters shed loads in a pre-established order when demand targets are about to be exceeded. There are two main algorithms used: simple, and predictive or slope-sensitive. Simple demand limiters can result in undesirably high load-shedding frequencies and cannot control demand closely.

3 **Generators** can be used to keep equipment operating while off grid. If the same generators provide emergency backup power, precautions must be taken to ensure emergency power availability even during peak periods. If critical loads also contribute to facility peaks, consider shifting these loads to generator power during peak periods.

4 **Dual-fuel heating and cooling** equipment can provide nonelectric means of meeting space-conditioning needs during times when using electricity would be expensive. For example, hybrid cooling systems, fueled by either natural gas or electricity, can dramatically lower electricity demand by using natural gas at peak hours.

5 **Battery storage** may not yet be cost-effective for peak reduction in most situations unless batteries are in place for other purposes. One example of where battery storage may make sense is for off-peak charging of forklifts used during daylight hours.

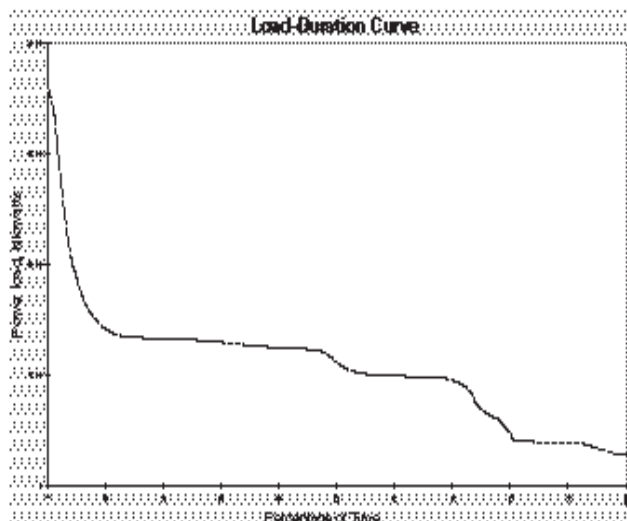
6 **Thermal storage** involves storing thermal capacity generated off-peak for on-peak use. During the peak periods of the day, circulating water is cooled by ice baths or chilled water tanks instead of chillers to provide space or process cooling. Heat storage is not as common as ice storage because of the extra volumes needed to store thermal energy without phase changes.

7 **Dispatchable load shedding** is a direct load-control technique, where the utility controls when a customer's equipment is shed under a pre-arranged agreement. Such arrangements can benefit both parties and justify on-site generation or alternative fuels.

8 **Cogeneration** of electricity and steam from gas turbines may be cost-effective for large facilities.



Facilities with steep load-duration curves are well suited for application of peak-shaving technologies. Load-duration curves, such as the one shown, are generated by sorting electri-



High Loads, occurring only a small percentage of the time, can lead to very large demand charges.

cal loads recorded for each hour of the year. Data may be available from the electrical utility or from the facility's energy management system.

With the use of dimmable lighting ballasts, both lighting and subsequent chiller loads can be reduced. Allowing the HVAC to drift slightly is another effective strategy. According to ASHRAE, one-hour excursions out of the standard comfort envelope will be unnoticeable to most occupants.



Track load factors each month to check the utility's demand charges. The formula to calculate load factor (LF) is shown below. Load factors greater than 100% are impossible and indicate metering or billing problems. Load factors that suddenly deviate from historical values also indicate problems. If problems are found, recheck the billing information and contact the utility.

Monthly kWh

Monthly peak kW x 24 x # days in billing period

If the facility has a high minimum-demand billing, check if the utility has a "ratchet release" provision to reset the minimum demand to a lower level based on measures implemented by the facility.

The building shell can be considered the primary component of any facility since it is the protective skin that allows both a controlled environment and protection for the building occupants. Consisting of the building's skin, roof, windows, and doors, the shell controls the flow of energy between the interior and exterior of the building. Facility managers have limited ability to change most of these components on a routine basis. However windows and insulation are two factors that can be readily upgraded as a strategy in routine building improvements. Reducing outside air infiltration into the building by improving building tightness should be one of the strategies used to conserve energy.

Action Moment

When reroofing or renovating spaces, be sure to determine if there is an opportunity to upgrade windows, doors, or insulation. Reducing infiltration may be possible during routine maintenance or when remodeling occurs.



Windows

1 **Glazing systems** present an excellent opportunity for energy savings. The strategy will vary greatly as a function of the location of the facility. In hot climates, the primary strategy is to control thermal radiation by keeping solar energy from entering the interior space while allowing visible light through for daylighting. Solar screens that intercept solar radiation, or films that prevent infrared transmission while allowing good visibility, are useful for hot climates.

2 **In colder climates**, the focus shifts from keeping solar energy from entering the space to reducing the interior conduction of energy from the warm to a very cold exterior. Windows with two or three glazing layers that utilize low-emissivity coatings will minimize conductive energy transmission. Filling the spaces between the glazing layers with an inert low-conductivity gas, such as argon, will further reduce heat flow.



Properly placed automatic doors and vestibules can reduce unwanted air leakage in buildings. Ensure the outdoor areas where people congregate, such as smoking areas, are not within electronic "view" of the automatic controls.

3 **Fenestration can be a source of discomfort** when solar gain and glare impact at the work station or other occupant zones. Daylighting benefits will be negated if other factors force occupants to use blinds, for example, to control unpleasant impacts.

4 **Facility managers should choose appropriate window technology** that is cost-effective for the climatic conditions. For example, double-glazing may be inappropriate in South Florida where solar films are the technology of choice. However, double-glazing is cost effective for the middle and northern latitudes of the United States.

5 **In cold climates** make sure that the frame is designed to prevent condensation. Both the frame and sash should have thermal breaks.



Walls and Roofs

For buildings with a primary cooling load, exterior finishes that have high reflectiveness and wall-shading devices reduce the solar radiation load, and consequently the HVAC load. Reflective finishes for the roof will help reduce loads because the roof is exposed to sun loads for the entire operating day. Metal, concrete tile, concrete shingle, aluminum shingles, and single-ply roofing systems are all available in reflective colors at no additional cost.

1 **Wall shading** can significantly reduce thermal loads on the envelope through roof overhangs, sun shades, or a canopy of mature trees.

2 **Light-colored roofs** have a beneficial effect in areas where cooling is the predominant air-conditioning requirement.

3 **In new construction**, a well-designed building envelope can significantly reduce the need for space conditioning, resulting in both initial and operating cost savings for the HVAC sys-



Insulation

1 **Insulation for most commercial buildings** is difficult to upgrade without expensive building modifications. Exterior finish insulation systems (EFISs) (insulation and exterior finish) can be added externally to some buildings to both increase the thermal resistance of the building shell and to improve the building's appearance.

2 **In cooling latitudes**, the addition of insulation has positive impacts on air conditioning to a point, and diminishing returns thereafter. Roofs and attics should receive priority attention for the addition of insulation, particularly during roof replacement.



Insulation is a guideline item under RCRA §6002 and should be purchased with recycled content.

Windows allow for daylight, winter solar gain, natural ventilation, and views. Glazing units are often the weakest point in the building envelope, thermally as well as acoustically. Types of glazing include clear, tinted, reflective, spectrally-selective, low-emissivity (low-e), Heat Mirror®, electrochromic, photochromic, thermochromic, photovoltaic, and transparent insulating. Window units with air, gases, and films within multiple panes are also available. Glazing units can be vertical, sloped, roof monitors, and skylights. High quality windows provide important comfort benefits in addition to energy savings.

Action Moment

Renovations afford opportunities for replacing older, clear, and single-glazed windows. A window retrofit always can be considered independently of other building changes. Improving the energy efficiency of windows without replacing the window units can be done at any time by adding shading devices and storm windows on the exterior, or by adding window treatments such as shades, shutters, window films, and drapes on the interior.



Technical Information

A window is defined by its solar heat gain coefficient (SHGC), U-value, air-leakage rate, visible light transmittance, and materials of construction. The materials and quality of construction will determine its environmental impact, maintenance, durability, and ability to be disassembled for reuse or recycling at the end of its life.

1 Issues to be considered in the selection of windows involve the glazing system, the framing system materials, window operation, the joints between the glazing unit and window frame and between window frame and wall. Windows allow

heat movement through conduction across the glazing and the frame, infiltration and exfiltration at the frame gaps and between the frame and wall, and solar radiation through the glazing. Window thermal performance should be compared by using the whole-window U-value. This includes the glazing, the frame, and any insulating glass spacers in multiple-glazing units. The lower the U-value ($\text{Btu} / \text{hr} \times \text{ft}^2 \times ^\circ\text{F}$), the better the performance. The U-value of single clear glazing is 1.1, or an R-value of 0.9.

2 Multiple glazing makes use of the insulation created by a gas-filled gap between the panes, which reduces conductive heat loss or gain. Typical gases are air, sulfur hexafluoride, carbon dioxide, argon, krypton, and xenon. These gases have lower thermal conductivity, thereby creating lower U-values within a smaller gap.

3 Spectrally selective glazings should be considered for windows in climates where solar gain in the summer creates large cooling loads, and where daylight also is preferred. These glazings have chemical coatings that allow specific portions of the energy spectrum to be transmitted.

4 In renovations—particularly of historic buildings—aluminum, metal and vinyl panning and receptor systems provide a weathertight, finished covering for placement over existing wood frames. This simplifies installation of new units and eliminates the removal of old frames.



Wood frames may be a better material from an environmental standpoint. However, they have greater life-cycle costs because of their shorter life, and higher maintenance costs compared to metal and plastic windows. The emphasis when selecting frame materials should be on thermal performance and maintenance, rather than the initial environmental impact of the material.

1 **Select windows for the best** combination of solar heat gain prevention, low SHGC ($SHGC < 0.4$) and high visible light transmittance ($V_t > 0.6$) for exposures other than south. An excellent choice for the combination of reducing solar gain and maximizing daylight gain is the use of double-glazed air-filled clear glass, with or without low-e coating, and external shading devices.

2 **The best methods for increasing the acoustical performance of windows** are to ensure that windows are airtight, and to increase the thickness of the glass. Increasing the thickness of a single pane from 12 mm to 25 mm will increase sound reduction by 10 decibels.

3 **The use of many types of inert gases**, air, and carbon dioxide in multiple-glazing units must be considered in the context of the environmental costs of producing these windows and the net benefit received from reduction of energy use. Air fill in a double-glazed window with a single low-e coating requires no energy for extraction, and can provide a greater net reduction of CO_2 production over the 20-year life of the window than the use of argon, krypton, or xenon.

4 **The choice of either fixed glazing units or operable units** should always be based on site-specific and climate-specific opportunities and constraints. Casement, pivoting, and awning windows offer the greatest opening area for natural ventilation and utilize compression seals that provide the best method of sealing the joint between sash and frame. Fixed windows provide the best thermal performance because of fixed seals, and can be designed to satisfy acoustical and security concerns as well.



Glazing that insulates poorly and highly conductive frames will have a colder interior surface than the inside of exterior wall surfaces in wintertime. Warmer, humid, interior air can condense on the inside of the glass and frames. This damages window frames, sills, wallboard, paint, and wallcoverings. A more thermally efficient window and a nonconductive frame with thermal breaks is less likely to cause condensation. Avoid metal frames that lack thermal breaks.

Facility managers should be aware of the advantages and disadvantages of using custom or stock windows for replacements. While custom windows will have a greater unit cost, they do not require additional adaptation devices and labor to modify the window unit or the framed opening that stock windows can require. The most economical materials for custom windows are aluminum, vinyl, fiberglass, and steel.

References

Arasten, D., "Advances in Window Technology," Lawrence Berkeley National Laboratory, Report 36891, February 1996.

Carmody, J., S. Selcowitz, and L. Heshong, *Residential Windows*, W.M. Norton and Co., 1996.

Contacts

The FEMP Help Desk at (800) DOE-EREC can provide window evaluation software developed by Lawrence Berkeley National Laboratory.

The National Fenestration Rating Council (NFRC) (301) 589-NFRC or at <http://eande.lbl.gov/BTP/NFRC> can provide information on the window rating labels that they developed.

Insulation provides resistance to the conductive flow of heat from either the exterior to the interior, or vice versa. The thermal resistance is measured in R-value: $(\text{ft}^2 \times \text{hr} \times ^\circ\text{F})/\text{Btu}$. The primary forms of building envelope insulation are loose fill, batt, rigid board, and foamed-in-place. Insulation, together with moisture barriers and vapor barriers, provides the means to control the passage of sensible and latent heat and prevent condensation at the building envelope. Because insulation represents a small portion of building costs and has a major impact on operating cost, it offers one of the most economical and effective measures a facility manager can take to reduce the environmental impacts of their buildings.

Action Moment

The ability to make improvements in insulation is highly dependent upon the type of insulation used and its location in the building envelope. Improvements to cavity insulation will be disruptive to building operations and require blown-in or foamed-in-place insulation. Methods such as exterior insulation and finish systems (EIFSs) can be used over existing exterior wall finishes independently of other changes. Exterior built-up roof insulation can be removed and reapplied in conjunction with reroofing on low-slope roofs. Gasketing and caulking are an integral part of insulating envelopes for energy efficiency and can be done independently, or in conjunction with insulation upgrades. Insulation must be purchased with recycled content according to RCRA §6002. Re-roofing and renovation are good opportunities to consider insulation upgrades.



Technical Issues

1 Critical selection issues for insulation are high R-value over time, minimal environmental impacts in their manufacture, long life, minimal replacement and landfill waste—including waste generated during installation—and minimal health

hazards to producers, installers and building occupants.

2 Two of the most critical environmental impacts of insulation are the use of CFCs for blowing agents, and the health concerns generated by fibrous materials such as asbestos and fiberglass.

3 When specifying insulation, a facility manager can ascertain the blowing agents that are used for board and foam insulation and look for alternative blowing agents such as steam, carbon dioxide, and pentane.

4 Moisture in the exterior wall cavity occurs when water is trapped in the wall cavity by impermeable surfaces and by condensation if the dew point temperature occurs at the exterior side of the wallboard. Eliminating moisture barriers and placing additional rigid insulation behind the interior wallboard of a stud wall will allow moisture to permeate from the wall cavity and reduce the temperature extremes between the warm back-side of the interior wallboard and the wall cavity.

5 Vapor barriers go on the "warm side" of building insulation. This means that in climates where cooling predominates, vapor barriers go on the outside of insulation. In climates where heating predominates, vapor barriers go on the inside of the insulation. Vapor barriers should be used instead of moisture barriers in warm-humid climates to prevent moisture buildup at the wall cavity. In warm climates, beware of interior wall treatments that act as vapor barriers.



Choose insulation based on its life-span.

This solves several issues at the same time: minimal maintenance and replacement, avoidance of landfill waste, more efficient use of nonrenewable resources, and higher return on investments over the life of the building. The insulation selected should have a minimum service life of 30 to 50 years.

1 **There are many choices for insulation materials** with excellent R-values and low environmental impact. Some of these include cellulose insulation made from recycled paper and boric acid, cotton insulation made from textile mill waste, and cementitious, isocyanurate, and urethane foamed-in-place insulation.

2 **Encapsulated fiberglass batt insulation** is available as a substitute for typical batt blankets in order to contain the dispersal of fiberglass fibers in installation. Fiberglass is also available without formaldehyde as a binder in limited parts of the country.

3 **Consider the insulation that best suits the cavity type and ease of access.** Foamed-in-place and blown insulations will best suit renovations where interior sheathing is to remain as undamaged as possible.

\$ **The economic return on greater insulation thickness** does not follow a linear relationship between savings and increased thickness. Facility managers should be aware of diminishing returns depending on the geographic location of the facility and the limitations of the type of insulation.

Settling, dust, and moisture accumulation reduce the R-value of loose fill and batt insulation, especially in vertical wall cavities. Appropriate installation with spacers or foamed-in-place insulation in cavity walls can avoid this problem.



Be aware of the potential health hazards associated with fibrous insulation. Asbestos is a proven carcinogen and is prohibited in all buildings. The debate on the hazards of fiberglass and mineral wool is ongoing. Caution suggests that existing asbestos, fiberglass, and mineral wool insulation should be left in place and encapsulated with the addition of insulation, when conditions permit. When removal is required, all relevant regulations and methods for removal, transportation and disposal should be followed.

Thermal bypasses in the building can significantly reduce insulation effectiveness. Thermal interfaces and gaps need to be sealed.



The Audubon Society's Audubon House in New York is a renovation of an existing building. Cementitious foamed-in-place insulation was used to fill cavity walls and increase the airtightness of the envelope, as well as to ensure excellent indoor environmental quality.

Passive solar design measures minimize use of mechanical systems and nonrenewable fuels. Passive solar design is a design approach that takes maximum advantage of nature and integrates building components—walls, windows, materials, lighting, mechanical systems—to reduce energy costs and fuel use. Passive solar strategies include daylighting; energy-efficient glazing; proper building form and orientation to the sun; natural cooling using ventilation and shading for most larger non-residential buildings; and passive solar heating of smaller buildings (less than 20,000 sq. ft.) in cold climates. The passive features are designed to integrate and interact optimally with the building envelope, HVAC, and lighting systems.



This passive solar building incorporates trombe walls, daylighting, and awnings.

Action Moment

Any renovation or addition to a building envelope offers opportunities for integration of passive methods. The best time to incorporate passive solar is early in the design process, or when the addition or building is first conceived. Ideally, an energy budget is included in the building design specifications, and the Requests for Proposal require the design team to demonstrate their commitment to whole building performance and their ability to respond to the energy targets. The commitment is emphasized during programming and throughout the design and construction process.

For retrofit projects, consider daylighting strategies, such as making atriums out of courtyards, or adding clerestories; heat control techniques such as adding exterior shades; and redoing HVAC systems and lighting systems, perhaps down-sizing if the passive strategies reduce energy loads sufficiently.

Many buildings in the Federal inventory have passive features because they were built before modern lighting and HVAC technologies were available. When renovating older buildings, determine whether passive features that have been disabled can be revitalized.



Technical Information

1

Highlight passive solar as a project goal.

Many agencies, including the GSA and the DOD, already have agency document language encouraging the use of passive solar design and renewables in all new construction and major renovation wherever feasible. An example of a good general project goal is “to produce a beautiful, sustainable, cost-effective building that meets its program, enhances productivity, and consumes as little non-renewable energy as possible through the use of passive solar design, energy efficiency, and the use of other renewable resources.”

2

Incorporating energy performance goals into the programming documents

conveys the seriousness of energy consumption and the use of passive solar as a design issue. For small offices, warehouses, and other smaller (10,000 sq ft or less) projects, facility managers or their contractors can develop energy budgets themselves easily using energy software such as ENERGY-10. For larger multi-zone projects (for example, laboratories or high-rise office buildings), national average

energy consumption data by building type can be cited as targets to be exceeded, or more complex analyses can be run by consultants.

3 **Thirty percent to fifty percent energy cost reductions below national averages are economically realistic** in new office design if an optimum mix of energy conservation and passive solar design strategies is applied to the building design. Annual savings of \$0.45 to \$0.75 per sq ft are a reasonable estimate of maximum possible cost savings.



Passive solar design considers the synergy among all the building systems. For example:

- Can natural light reduce the need for electric light?
- If less electric light creates less heat, will there be a lower cooling load?
- If the cooling load is lower, can the fans be smaller?
- Will natural ventilation allow these fans to be turned off at times?

1 **Don't look for generic design solutions or rules-of-thumb** because there are so many possible combinations and system interactions. Some of the variables involved include: climate (sun, wind, air temperature, and humidity); building orientation (glazing and room layout); building use type (occupancy schedules and use profiles); lighting and daylighting (electric and natural light sources); building envelope (geometry, insulation, fenestration, air leakage, ventilation, shading, thermal mass, color); internal heat gains (from lighting, office equipment, machinery, and people); HVAC (plant, systems and controls); and energy price (fuel source, demand charges, conversion efficiency).

2 **The integrated interaction of at least 16 energy-efficient strategies** are considered in passive solar design. They are: daylighting; glazing; shading; energy-efficient lighting; lighting controls; insulation; air-leakage control; thermal mass;

passive solar heating; natural ventilation; economizer cycle; exhaust air heat recovery; high-efficiency HVAC; HVAC controls; evaporative cooling; and solar water heating.



Passive solar design is an integrated design approach that optimizes total building performance rather than a single building system. This is the key to "green building" design.



Buildings designed using passive design technologies are generally more comfortable for the occupants, resulting in productivity benefits that are great relative to the building cost.

Cost analysis is conducted at the same time as technical analysis in a passive solar design in order to optimize investments for maximum energy cost savings.

References

Olgay, Victor, *Design with Climate: Bioclimatic Approach to Architectural Regionalism*, Princeton University Press, Princeton, NJ, 1963.

Watson, Donald, *Climatic Design: Energy-Efficient Building Principles and Practices*, McGraw-Hill, New York, NY, 1983.

Contacts

FEMP offers a course on passive solar design, *Designing Low Energy Buildings*. Call (800) DOE-EREC for course information.

Passive Solar Industries Council (PSIC), 1511 K St. NW, Suite 600, Washington, DC 20005 (202) 628-7400 or at <http://www.psic.org> has developed a software package called "ENERGY-10" to evaluate passive measures in smaller industrial buildings.

As the rate of fossil fuel resource depletion accelerates due to pressures from emerging economies worldwide, prices are likely to rise. Conversely, technology and manufacturing advances have brought the cost of renewable energy use, such as solar and wind, down significantly. In the near future, power generated from renewable resources and by alternative methods of power generation will have significant cost advantages over conventional hydrocarbon systems. In the near term, there are niche applications, such as remote photovoltaics and solar swimming pool heating where renewables have a definite cost advantage. Because they are pollution-free, renewables have huge advantages when environmental impacts are considered. Wind power has already broken through the cost barrier that historically prevented the large-scale introduction of sustainable energy systems. Over 3,500 MW of wind energy generating capacity have been installed worldwide. Photovoltaics and fuel cells also are beginning to emerge as strong competitors for conventional power systems, with over 500 MW installed worldwide.

Action Moment

When adding power generation capacity for a site or large facility, be sure to investigate the potential for renewable and alternative energy systems. In addition to their low environmental impacts, they will become more cost advantageous each year as the costs of conventional fuels rise. On-site power generation from renewable energy resources provides the added potential of reducing peak power demand with significant savings per peak kWh. Life-cycle costing comparisons between renewable energy systems and conventional power generation should include forecasted demand reduction as a cost component in favor of renewable energy.



Technical Information

1 Photovoltaic power systems are rapidly becoming competitive with conventional power systems, especially where the cost of infrastructure to



This solar-hydrogen fuel cell at the Telsonicher Marine Lab in Trinidad, California, serves as a research and demonstration project.

deliver power to a site is relatively high. Photovoltaics should be given serious consideration for isolated or remote applications and structures because of the high cost of power line installation. Photovoltaics are competitive with diesel or propane generators. Hybrid photovoltaic/generator systems combine the low operating cost of photovoltaic with the availability of generator power. Additional information on photovoltaic technology is provided in section 3.10.1.

2

Wind energy systems, covered in section 3.10.2, can generate electrical power more cheaply than fossil fuel systems, with rates as low as \$0.039/kWh. The wide range of mechanical and electrical components required for wind power generation creates demand for many sophisticated components, thereby keeping expenditures for energy in the domestic economy. Because winds on the order of 13 miles per hour average are required, not every region is suitable for economically generating energy from wind. Wind turbines may not be suitable in populated areas, and local topography can either accentuate or attenuate wind patterns. However, much of the United States and many overseas locations are excellent places for wind energy systems, and their many advantages warrant their serious consideration.

3 Fuel cells are electrochemical engines that convert the chemical energy of a fuel and an oxidant directly into electricity. The principal components are catalytically activated electrodes for the fuel (anode) and the oxidant (cathode) and an electrolyte to conduct ions between the two electrodes. Because the operating conditions of the fuel cell are largely determined by the electrolyte type, fuel cells are classified by the type of electrolyte. They have high power generation efficiency, and perhaps most importantly, they pave the way for the transition to what many consider to be the replacement for hydrocarbon fuels: hydrogen. DOE has several active programs that can assist the facility manager in acquiring fuel cells for their location. Section 3.10.3 contains information and points of contact for these programs.

4 Federal Renewable Energy Screening Assistant (FRESA) is a software tool used to identify retrofit opportunities that are most likely to use renewable energy cost-effectively. This allows users to better focus on analytical resources. FRESA screens for 15 renewable energy, conservation, and power generation options, including active solar heating and cooling, solar water heating, daylighting, solar thermal electric, wind, small hydro, electricity from biomass and waste, and load avoidance by building envelope improvements. The reports FRESA generates are consistent with the DOE/FEMP SAVEnergyAudit format.

When performing a life-cycle costing of renewable or alternative energy systems, forecasting fuel price changes over a system's lifetime is, of course, very difficult. NIST provides several publications that can assist the facility manager with this type of information.

References

National Institute of Standards and Technology, *DISCOUNT: A Program for Discounting Computations in Life-Cycle Cost Analyses*, (NISTIR 4513). A program for computing discount factors. Be sure to ask for the latest version.

National Institute of Standards and Technology, *Present Worth Factors for Life-Cycle Cost Studies in the Department of Defense*, (NISTIR 4842-2). A separate version of the report listed above, for DOD analyses.

See section 2.2 for more information on life-cycle cost analysis.

Contacts

The FEMP Help Desk at (800) DOE-EREC has information on the latest developments in wind energy, photovoltaics, fuel cells, and other "green" energy technologies, as well as the FRESA software.

Photovoltaics (PV) or photovoltaic cells are devices that convert light into electricity. Although there are several photovoltaic technologies, the typical cell is a thin rectangular or circular wafer made of boron-doped silicon sandwiched with a wafer of phosphorous-doped silicon. The wafers are wired together in modules. Thin-film technologies deposit the PV material directly onto glass, plastic, or metal substrate. Especially exciting are products that integrate PV directly into building materials such as glass, flexible shingles, and raised-seam metal roofing.

Action Moment

The present trend in pricing is rapidly making PV competitive with conventional power systems, especially where the cost of infrastructure to deliver power to a site is relatively expensive, such as extending a new power line or operation of a generator at a remote site. Give PV serious consideration for isolated or remote applications and structures because the cost of power line installation is very expensive. Consider replacing diesel generators with PV in environmentally sensitive areas where fuel spills are a special problem.

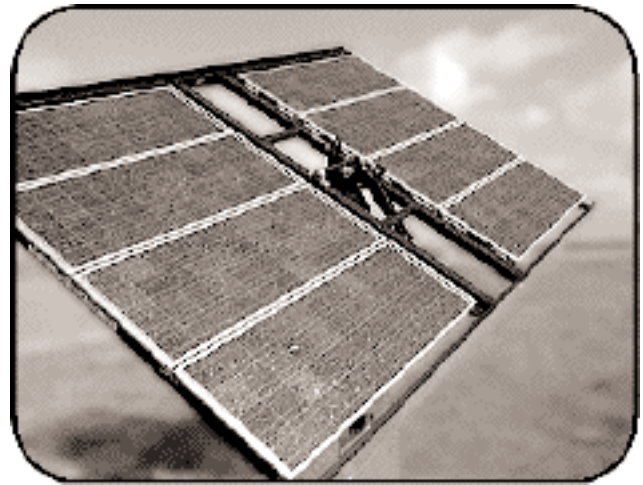


Technical Information

There are two basic PV system types for any given application. The first are stand-alone systems with battery storage, hybrid PV/generator systems with a diesel or propane generator as back-up. The second are utility-interactive (grid-connected) systems with PV as the primary power source and the utility grid as the backup.

Manufacturers use several types of semiconductor materials in photovoltaic cells: single crystal silicon, polycrystalline silicon, hydrogenated thin-film amorphous silicon, cadmium telluride, copper indium diselenide, gallium arsenide, and others.

1 *Thick-cell photovoltaics* are on the order of 4 to 17 mils thick and are comprised of single-crystal or polycrystalline silicon. *Thin-cell photo-*



Photovoltaic panels are frequently mounted on devices that track the sun.

voltaics are less than 5 microns thick, require far less material, and are extremely lightweight.

2

Thin-film photovoltaic cells are typically 6% efficient in converting light to electricity. *Thick-film* cells have efficiencies on the order of 16%.



Stand-alone systems can be set up to function in several ways:

1

A direct-coupled system is the simplest version and consists of photovoltaic cells driving a DC load with no battery storage. Loads such as water pumps, ventilation fans, and special DC refrigerators are good applications.

2

Battery storage systems to drive DC loads. These systems store the energy until it is needed, for example, in powering navigational aids at night. The simplest version drives DC loads only, and may require a battery system with charge control if the loads are variable.

3

Battery storage systems to drive DC or AC loads. These systems have an inverter and charge controller to drive connected AC loads. A hybrid version has one or more energy sources such as a wind or motor generator set to supplement battery charging.

Some good stand-alone applications: Backup power and emergency communications; irrigation systems for agriculture; microwave repeaters; cathodic protection for bridges, pipelines, towers, and wellheads; navigational aids; security systems; environmental sensors such as radiation monitors; meteorological stations; noise monitors; and area and signboard lighting.



Utility-interactive systems or grid-connected systems require an interface to operate with the grid. The PV power is delivered first to the load. Any excess power is fed back into the grid. These systems require synchronous inverters that not only convert DC into AC power, but also match the output power to the phase and frequency of the grid. Some considerations for these systems:

1 Public Utilities Regulatory Policy Act (PURPA) requires utilities to interconnect to any qualified facility. However, the facility must pay for the interconnection.

2 The technical and operating issues that must be coordinated with the utility are: metering, safety, equipment protection, service reliability, and power quality.

3 When planning a utility-interactive system, be sure to check into metering options, buy and sell rates for power, outdoor disconnect requirements, insurance requirements, and interconnection costs.

4 Selecting a PV array is an important element in creating the PV system. The following basic information is required to select and procure a PV array:

Selection criteria: voltage-current characteristics; long term reliability; power output density; dimensions and weight; manufacturer's reputation; cost and warranty; framing materials; suitability for high-temperature operation and self-regulation.

Procurement specifications should contain: module manufacturer and model number; module dimensions; wiring arrangement; junction box configuration; module max power; max current; short

circuit current; open circuit voltage and other rating conditions; module framing and fastening systems; grounding arrangements; instrumentation and provisions for diagnostics; array circuit disconnect arrangement; array bypass diode arrangement.



In 1970 photovoltaic cells cost over \$1,000 per peak watt of power and were used solely for exotic applications such as spacecraft power systems. Prices today are under \$5 per peak watt, and power stations of the multiple megawatt range are under development.



Storage systems for PV arrays provide the owner the capability of using the captured energy at night or at other off-peak times. The typical storage system is a set of batteries sized to accommodate the PV input as well as the load demand. Additional benefits of a battery storage system are: (1) power is supplied at stable voltages and the transient peaks from the PV system are smoothed out; and, (2) transient peak loads coming on and off line can be supplied the necessary electrical power at the exact time it is needed.



When selecting a battery system, the designer needs to consider size and weight, cost, warranty, availability, reputation of the manufacturer, maintenance requirements, cyclic and calendar life, daily depth of discharge, temperature and environmental conditions, off-gassing characteristics, and terminal configuration.

References

Department of Energy, National Renewable Energy Laboratory, *Photovoltaic Fundamentals*, (DOE/CH10093-117, Revised Feb 1996).

Florida Solar Energy Center, *Photovoltaic System Design Manual*, (FSC-GP-31-86, Revised April 1996), Cape Canaveral, FL

Solar Energy Industries Association, 122 C St, N.W., Washington, D.C. 20001 (202) 383-2600.

Contacts

Contact the FEMP Help Desk at (800) DOE-EREC, or the FEMP Home Page at <http://www.eren.doe/femp>.

Wind power is perhaps the biggest success story in the arena of alternative or renewable energy systems. At present, power generation by wind turbines is competitive with fossil fuel and nuclear power. A new National Wind Technology Center was recently opened by NREL in a collaborative effort among industry, utilities, environmental groups, and others. Over 3,500 MW of windpower generating capacity have been installed worldwide.

Action Moment

Wind power is an excellent choice for providing power for large sites with high electricity prices and where the prevailing winds exceed 21 kilometers (13 miles) per hour for 90% of the year. Wind electric turbines that generate power at under 5¢/kWh are available in sizes from 1 to 500 kW. If necessary they can be grouped together in farms to supply larger requirements.



Technical Information

The grid-connected capacity of wind energy systems in the United States was 1,717 MW in 1994, almost half of the world's total installed wind capacity. However, at present, the rest of the world is installing wind energy capacity at 10 times the U.S. rate. For example, India is expected to add up to 1,200 MW of wind energy systems in the period 1994 to 2000.

1 **Wind energy systems help the U.S. economy** by creating demand for a wide range of components, including: wind electric turbine blades, gearboxes, generators, electronic controls, and towers.

2 **There are two basic wind electric turbine designs:** vertical axis machines that look like “egg beaters” and horizontal machines that look like propellers. The latter comprise 95% of the installed utility-scale (larger than 250 kW) turbines.

3 **Hybrid wind/diesel systems** are available that utilize wind energy generation to the maxi-



Wind power systems now produce electricity cheaper than fossil fuel plants and are the major success story in renewable energy.

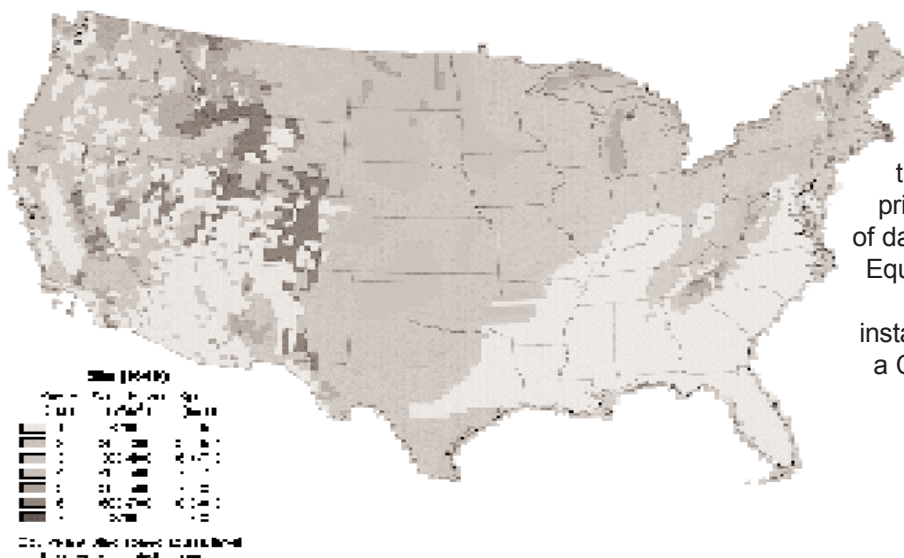
imum extent possible, while still providing reliable and economical power.

4 **Wind electric turbine systems for small-scale rural electrification** have been in use since the 1930s and require an annual average wind speed in excess of 13 kilometers per hour (8 mph) to be economical.

5 **Wind energy systems** also are available for roles other than generating electricity for the grid. Water pumping systems are available that lift water directly through mechanical means, or that generate electricity for electric pumps.

6 **Wind energy developers** are now bidding utility-scale projects as low as 3.9¢/kWh, an almost 80% reduction from the costs of the first wind energy projects that were installed at a cost of 30¢/kWh in 1981. Many people are forecasting that in the next 10 to 15 years, wind energy will be the cheapest energy available from any source.

7 **Although some noise is generated** by wind turbine plants, a 300 kW wind turbine creates only 45 dB of noise at a 200 meter distance.



Wind Energy Resource Atlas of the United States
Map 2-5 Annual average wind resource estimates in the contiguous United States

To obtain accurate information on wind speeds in a given location or to increase the confidence level in wind data prior to executing a project, a year of data collection may be necessary. Equipment to accomplish this costs \$1,500 to \$3,000 and can be installed in one day. FEMP also has a CDROM containing wind speeds throughout the United States.

8 The power available from wind is proportional to the cube of its speed. By doubling wind speed, the power generated increases by a factor of 8. A generator operating in 19 kilometer per hour (12 mph) winds will generate 29% more electricity than one operating in a 18 kilometer per hour (11 mph) wind.

9 Approximately 20 hectares (50 acres) of land are required per MW of installed capacity. However much of the land is actually unoccupied and can be used for farming, ranching, and other activities. Systems range from 24 to 37 meters (80 to 120 feet) in height to avoid ground turbulence and to increase performance due to higher wind velocities at altitude.



The downsides of wind-turbine-generated electricity are the potential visual impacts and bird collisions. Efforts are being made to mitigate both of these effects. Using turbines of the same size and uniform spacing, plus the use of computer simulation to analyze the visual impacts can greatly improve the appearance of a wind farm. The National Audubon Society and others are working with the American Wind Energy Association to minimize bird impacts.

Wind energy carries a “production tax credit” for any wind turbines installed after December 31, 1993 and before July 1, 1999. The tax credit is

1.5¢/kWh generated and applies for the first ten years of the turbine’s operation. The Energy Policy Act of 1992 contained these provisions for stimulating the development of wind power.

References

American Wind Energy Association, *Small Wind Energy Systems Application Guide*, Washington, DC, 1993.

American Wind Energy Association, *Wind/Diesel Systems Architecture Guidebook*, AWEA Standard 10.1-1991, Washington, DC, 1991.

American Wind Energy Association, *Wind Energy for Sustainable Development*, Washington, DC, 1992.

Contacts

For a CDROM of windspeeds from around the United States, contact FEMP at (800) DOE-EREC.

American Wind Energy Association, 122 C Street, NW, Washington, DC, 20001 (202) 383-2500

National Renewable Energy Laboratory, National Wind Technology Center, 1617 Cole Blvd., Golden, CO, 80401 (303) 384-6900

National Wind Technology Center, NREL, 1617 Cole Blvd., Golden, CO, 80401 (303) 384-6900.

Fuel cells generate electricity by converting chemical energy into electrical power with no moving parts. Power generation via fuel cells is a rapidly emerging technology that provides electricity with high efficiency and low noise. Fuel cells provide the opportunity to transition from fossil fuels, such as natural gas, methane, and liquid hydrocarbons, to what many consider to be the fuel of the future: hydrogen. The oxygen used in the fuel cell is atmospheric oxygen and the hydrogen is either elemental hydrogen or hydrogen extracted from hydrocarbon fuels using a device called a *reformer*. Fuel cell power plants that produce up to 11,000 kW have been built from multiple 200 kW units.

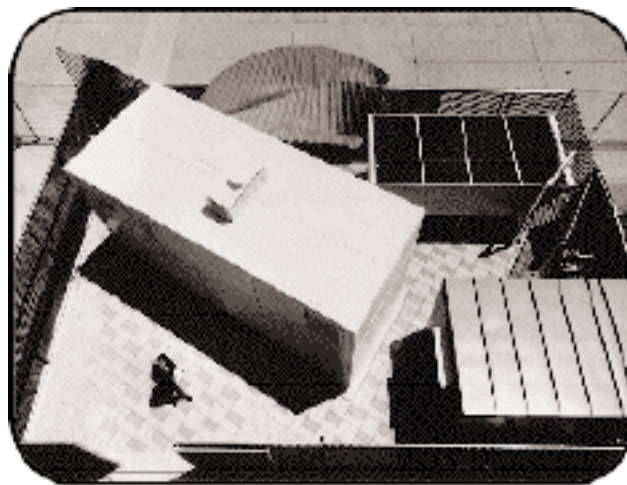
Action Moment

The Department of Energy and the Department of Defense have several programs to subsidize the purchase of fuel cells for use in a variety of applications. These programs are intended to create a “push” effect to accelerate the development of this technology. In a recent program, DOE earmarked \$15 million for grants to prospective buyers with priority being given to DOD installations. DOE is offering to pay \$1,000 per kW for Federal projects between 100 and 3,000 kW, not to exceed one-third of project costs. Contact the DOE’s Business Information Center about this program. (<http://www.metc.doe.gov/business/solicita.html>)



Technical Information

Fuel cells are electrochemical engines that convert the chemical energy of a fuel and an oxidant directly into electricity. The principal components are catalytically activated electrodes for the fuel (anode), the oxidant (cathode), and an electrolyte to conduct ions between the two electrodes. Because the operating conditions of the fuel cell are largely determined by the electrolyte, fuel cells are classified by the type of electrolyte.



This fuel cell powers some of the electrical systems at the Pittsburgh International Airport.

There are several fuel cell technologies being developed at present:

- 1** **Phosphoric acid** fuel cells (PAFC) have an acid electrolyte and are the most highly developed fuel cells. These have relatively low-temperature operation, around 200°C (400°F), produce on the order of 200 kW, and are commercially available.
- 2** Fuel cells using a **molten carbonate** (MCFC) electrolyte are relatively high-temperature units, operating in excess of 600°C (1100°F). MCFCs are being designed for larger-scale applications on the order of 50 to 100 MW. The high-temperature exhaust gases can be used in a combined cycle system, creating an overall efficiency on the order of 80%.
- 3** **Solid oxide** (SOFC) electrolyte fuel cells are also high-temperature devices, operating at 600 to 1000°C (1100 to 1800°F). At these temperatures a natural gas-powered fuel cell does not require a reformer. The solid construction of the SOFC fuel cell prevents some of the corrosion problems of liquid electrolyte fuel cells. A variety of 20 to 25 kW SOFC units have been tested, and units up to 150 kW are planned.

4 **Proton exchange membrane (PEM)** fuel cells are well-suited to mobile applications requiring relatively compact power systems. The electrochemistry of PEM fuel cells is similar to that of phosphoric acid fuel cells. They operate in the same pressure range, but at a much lower temperature, about 80°C (175°F). PEM cells are being used to power buses and automobiles. Their very low thermal and noise signatures may make them especially useful for replacing military generator sets.

Efficiencies as high as 70% have been observed for fuel cells in laboratory settings. Actual efficiencies of commercially available fuel cells range from 50% to 60%. In automotive applications the expected efficiency range is 36% to 50%, compared to 20% for current internal combustion systems.



Fuel cells are inherently less polluting than conventional fossil-fuel technologies and are more efficient in producing electricity. They produce almost no harmful air or water emissions. The principal by-product is water.

Fuel cell-powered vehicles are projected to save 2 billion to 4 billion barrels of oil per day by the year 2030. Total economic benefits are forecast to range from \$26 billion for methane-powered fuel cell vehicles to \$116 billion for hydrogen-powered vehicles.



The footprint of a 200 kW PAFC unit is about 20 m² (200 ft²), while the footprint of a 2.85 MW MCFC plant is about 450 m² (4,500 ft²).



Many types of fuel cell power plants must have their stack and fuel processor units replaced every 5 to 10 years, requiring a shutdown of several days for the replacement.



The U.S. Army Corps of Engineers Construction and Research Laboratory (CERL) plans to complete the distribution of eleven 200 kW PEM fuel cells to Department of Defense installations by the end of 1996.

Four parallel 15 kW fuel cells provide all the power required by the Space Shuttle once it is in orbit.

References

Department of Energy, Federal Energy Management Program, "Natural Gas Fuel Cells," *Federal Technology Alert*, Washington, DC. Available from the FEMP Help Desk at (800) DOE-EREC.

Contacts

Department of Energy, Morgantown Energy Technology Center, 3610 Collins Ferry Road, Morgantown, WV 26505, (304) 285-4086

Department of Energy, Office of Propulsion Systems, 1000 Independence Avenue SW, Washington, DC 20585, (202) 586-8055

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Department of Energy, National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, CO 80401 (303) 231-7681

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